Global Strategy for the Conservation and Use of *Musa* (Banana) Genetic Resources

A consultative document prepared by the Global *Musa* Genetic Resources Network (MusaNet)

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CHAPTER 12.
GENETIC IMPROVEMENT

SECTION 12.1 GENETIC IMPROVEMENT – WHERE WE ARE NOW

Genetic improvement presents a potentially cost-effective mechanism to address current constraints in smallholder and commercial production by providing high-performing cultivars adaptable to diverse environments.

Productivity, resilience and sustainability may be enhanced by integrating inter- and/or intra-crop diversity within production systems. Experiences with rice and other cereals, being extended to banana, suggest that the risks of losses from epidemic diseases can be mitigated by planting mixed genotypes in place of extensive monocrops of a single cultivar. A demand for increased diversity of cultivars, as well as improved cultivars, exists among smallholder farmers and formal market systems, as well as within the research and breeding community. Supplying producers with a wider range of diversity can potentially enable more livelihood options to be adopted and family nutrition to be similarly diversified.

This chapter does not intend to review banana breeding. For exhaustive recent reviews, the reader can refer to Ortiz et al. 1995, Bakry et al. 2009, Tenkouano et al. 2011, Ortiz 2013, and Ortiz and Swennen 2013.

12.1.1 Breeding objectives

Banana breeding began in the early 1920s, when all the large commercial plantations of banana for export in Central America were decimated by the Fusarium wilt caused by *Fusarium oxysporum* f. sp. *Cubense*. In response the first breeding program was initiated in Trinidad and Jamaica by the Imperial College of Tropical Agriculture (ICTA), paving the way for the implementation of several national programs some 40 years later. Meanwhile, the fungus spread around the world and reached all plantations of AAA Gros Michel, the then-predominant cultivar, so that banana export in the 1950s was at risk of disappearing. Fortunately, explorations of existing genetic resources showed the AAA 'Cavendish' cultivars to be resistant to the disease and suitable for export. These cultivars subsequently substituted 'Gros Michel' in all commercial export plantations worldwide and remain the predominant subgroup produced at the global level, both for export and domestic markets. Obviously, a production system based on such a narrow genetic base is extremely vulnerable to existing and emerging pests and diseases.

Until the 1970s, banana breeding strongly focused on export bananas, mainly led by ICTA and the United Fruit Company, who established the FHIA breeding program in Honduras. During the second half of the 20th century, several diseases and pests increasingly affected various banana types, thus menacing the production at the farm level as well: Sigatoka leaf diseases (yellow Sigatoka, followed by the more damaging black leaf streak), nematodes and weevil borers. More recently, the emergence and rapid spread of Fusarium wilt tropical race 4 in Asia, to which the Cavendish is susceptible, became an additional priority.

Consequently, from its initial focus on dessert export bananas, banana breeding expanded gradually to plantain and non-export dessert bananas in the 1970s, considering their importance as major staple foods and sources of income for millions of people in tropical and subtropical countries. National and international programs were established to address national, regional or global needs: IITA and CARBAP in Central and East-Africa, EMBRAPA in Brazil, CIRAD in the Caribbean, NRCB in India, etc. Despite the importance of bananas and plantains in food security, there are still only a small number of breeding programs. A major step towards a solution for such a critical situation was the establishment in 1985 of the International Network for Improvement of Banana and Plantain (INIBAP), now Bioversity International, in order to coordinate and stimulate collaboration within the banana research community, to facilitate the exchange of genetic resources and knowledge and to foster international cooperation.

Improvement for pest and disease resistance or tolerance is the primary objective of banana breeding, but the simple release of new resistant cultivars is insufficient for actual adoption by producers. Hybrids must respond to a wide number of criteria according to their specific cropping and socio-economic contexts. For export banana, breeding aims at cultivars that maintain or improve the productivity and the fruit quality (including post-harvest and transportation and conservation qualities) of Cavendish clones. For local consumption and domestic markets, most criteria are the same, even if post-harvest criteria are less constraining. Secondary objectives are linked to the diversity of cultivar growing environments, and include tolerance to cold, to drought stresses, short plant size and strong root system to avoid wind damage and optimise nutritional uptake, etc.

As stated by Ortiz (2013), “emphasis for banana genetic enhancement should be given to pre-emptive breeding – particularly through broadening approaches – to deal with new strains of major pathogens and pests, as well as other emerging constraints”.

12.1.2 Biological constraints

Most cultivated bananas are triploid (2n=3x=33), originating mostly from the two diploid species *M. acuminata* and *M. balbisiana* (2n=2x=22). Banana breeding faces a paradox: considerable amount of seeds are required to produce large progenies, but hybrids selected from these populations must not contain any seeds.

Wild species display few reproductive barriers: the male flowers have plenty of viable pollen and the fruits are full of seeds. One thousand to over 10,000 seeds per bunch can be found in wild *acuminata* or *balbisiana* species. Actually, breeding progress is hampered by the specific biology of cultivated bananas, i.e. low reproductive fertility of cultivars. Fruit sterility and parthenocarpy have been selected by growers at the diploid level throughout the long domestication history of this crop. At the diploid level, infertility is partly associated with structural heterozygosity, present in most cultivars, leading to aneuploid gametes bearing from 12 to 16 chromosomes. Fertility is zero in AB diploid cultivars because of the partial homeology between the *acuminata* and *balbisiana* chromosomes, whereas AA diploid cultivars show a wide range of male or female fertility. Although still rather low, their overall fertility is often higher than triploids: occurrence of aneuploid gametes and formation of diploid to tetraploid gametes are frequently reported at the triploid level. This results in little or no fertility in triploid cultivars, mainly due to the uneven number of chromosomes.

Even a profusely hand-pollinated bunch of a triploid cultivar rarely contains more than 1 to 5 good seeds, making the production of a significant offspring a great challenge. Beyond scarcity, seeds in cultivated clones are often abnormal, indeed, with the absence of embryo or endosperm, sometimes both, and fail to develop into seedlings. Greenhouse germination rates are rarely over 20%, and most banana breeders systematically resort to embryo rescue using tissue culture to increase the germination rate up to 85%.

12.1.3 Breeding approaches

For most banana breeders, the main strategy for genetic improvement of banana is to breed resistant triploid hybrids as final products. Triploid cultivars were proved to give a selective advantage over other ploidy levels: diploid cultivars are usually less productive and less vigorous although some diploid clones, like AAcv Pisang Mas of ABcv Kunnan are of some significant value but produced for small or niche markets with high added value. Tetraploid hybrids were the first resistant cultivars bred, and may actually be satisfying in terms of yield, bunch and fruit sizes. However, tetraploids occasionally contain seeds and their poorer fruit quality has never met the requirements for large scale adoption by markets and consumers.

Basically, two breeding philosophies have been elaborated by banana breeders. The first one has been called “Evolutionary breeding” (Tenkouano et al. 2011) and relies on the improvement of the triploid cultivars crossed with diploid cultivars. Since the method is not reproducing the evolution towards triploids via edible diploids (see Chapters 2 and 3), this document prefers to adopt the name “Pragmatic breeding”. The second approach, “Reconstructive breeding”, is built on the use of diploid germplasm to create triploid hybrids, thus trying to mimic the spontaneous development of the current triploid cultivars from their diploid ancestors in the past.

12.1.3.1 The « Pragmatic breeding » approach

The origin of this approach is at the dawn of banana breeding, when breeders tried to develop ‘Gros Michel’ hybrids resistant to Fusarium wilt. Triploid cultivars show a residual fertility and when crossed with diploid cultivars, may produce a few seeds. The primary products issued from these crosses show a considerable genotypic (and phenotypic) variation, ranging from diploid to highly polyploid hybrids. Among them, tetraploid hybrids, arising from unreduced triploid egg cells (2n=3x=33) were selected. The value of these hybrids is that the genes from the mother plant do not segregate and their main characteristics are maintained in the tetraploid, while the haploid genome added from the diploid confers disease resistance.

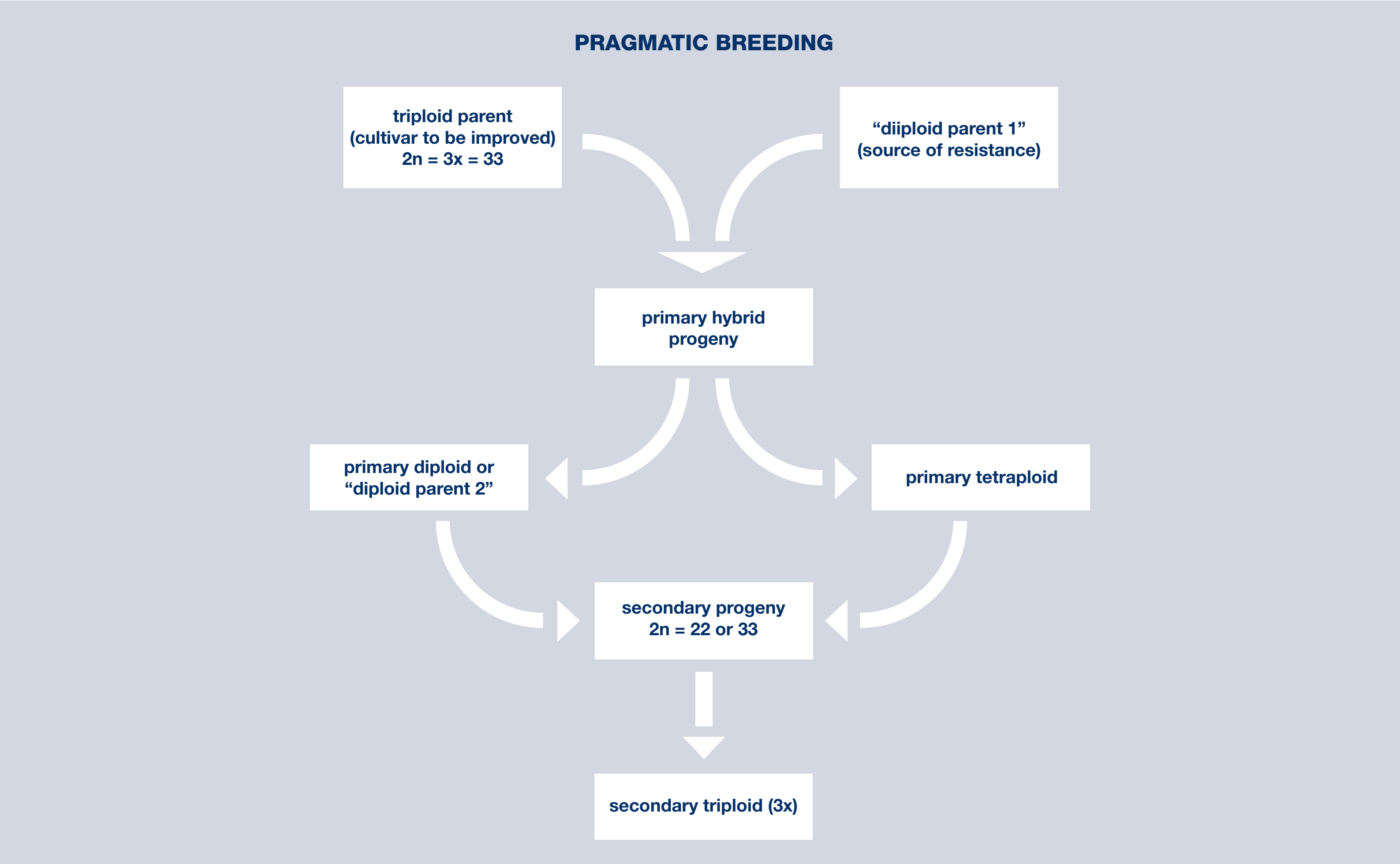
This strategy was taken up for other dessert and cooking bananas to confer resistance to black leaf streak and to nematodes. Dessert tetraploid hybrids were developed at FHIA from crosses between dwarf mutants of Gros Michel and Prata with improved diploids resistant to Sigatoka diseases and nematodes. Cooking bananas were developed from crosses between plantains and resistant diploids at IITA, CARBAP and FHIA to confer resistance to black leaf streak. Some outstanding hybrids were obtained by this strategy. FHIA21, a cooking tetraploid hybrid released by FHIA, is now being cultivated for local markets in some countries in West Africa, in Central and South America and in the Caribbean, as a substitute to black leaf streak susceptible plantains. A major outbreak of this approach is the discovery of endogenous integrated sequences of the endogenous banana streak virus (eBSV) in the plantain genome, releasing infectious viral particle in the progenies issued from crosses. However, these viral sequences have been shown to behave as pseudo-genes and can in some cases segregate as heterozygous locus (Gayral et al. 2008), paving the way for the elimination of infectious eBSV sequences.

Tetraploid hybrids, AAAB, AAAA and AABB (primary tetraploid hybrids) are often much more fertile than the triploid parent, and can produce seeds when crossed with a diploid accession. The descendants obtained from these 4x x 2x crosses are predominantly triploids (secondary triploid hybrids). Thanks to redistributions and recombinations between A and B chromosome during meiosis, triploid hybrids free from infectious eBSV can be obtained from theses crosses.

As mentioned above, the initial 3x x 2x cross also produces diploid hybrids, whose genetic background comes from the triploid mother plant. These primary diploid hybrids are eventually used in the 4x x 2x cross to bring additional mother-plant background to the secondary triploid hybrids.

In this breeding scheme, selected resistant primary tetraploid hybrids can be either released as new improved cultivars or subsequently crossed with other improved diploid selections to obtain secondary triploid hybrids. In this approach, the genetic diversity used on the triploid side is very limited, due to the low fertility of triploid cultivars. The choice of the diploid parents to be crossed in the first or second step is therefore crucial. Considering that the unreduced triploid eggs of the maternal parent are genetically homogenous, the breeding effort is only based on the improvement of the diploid parent. Within the great diversity of the diploid pool, wild and edible diploids have been selected to introgress pest and disease resistance in triploid cultivars. However, wild relatives are highly fertile but have very few of the outward appearances of cultivated bananas, while edible diploids, even if they are more attractive in terms of bunch appearance and fruit qualities, are at most moderately fertile and often not resistant to diseases. Consequently, pre-breeding at the diploid level appears as a preliminary step. Some elite diploids have been developed and used, the most notables are the AA hybrid M53 (resistant to Sigatoka diseases and to Fusarium wilt), bred in the 1950s by the breeding programme of the former Jamaican Banana Board, and several outstanding diploids created at FHIA, some of which have multiple resistance (to Sigatoka diseases, nematodes and Fusarium wilt) and a huge number of hands.

Figure 12.1. *Pragmatic Breeding (Source: J. P. Horry)*



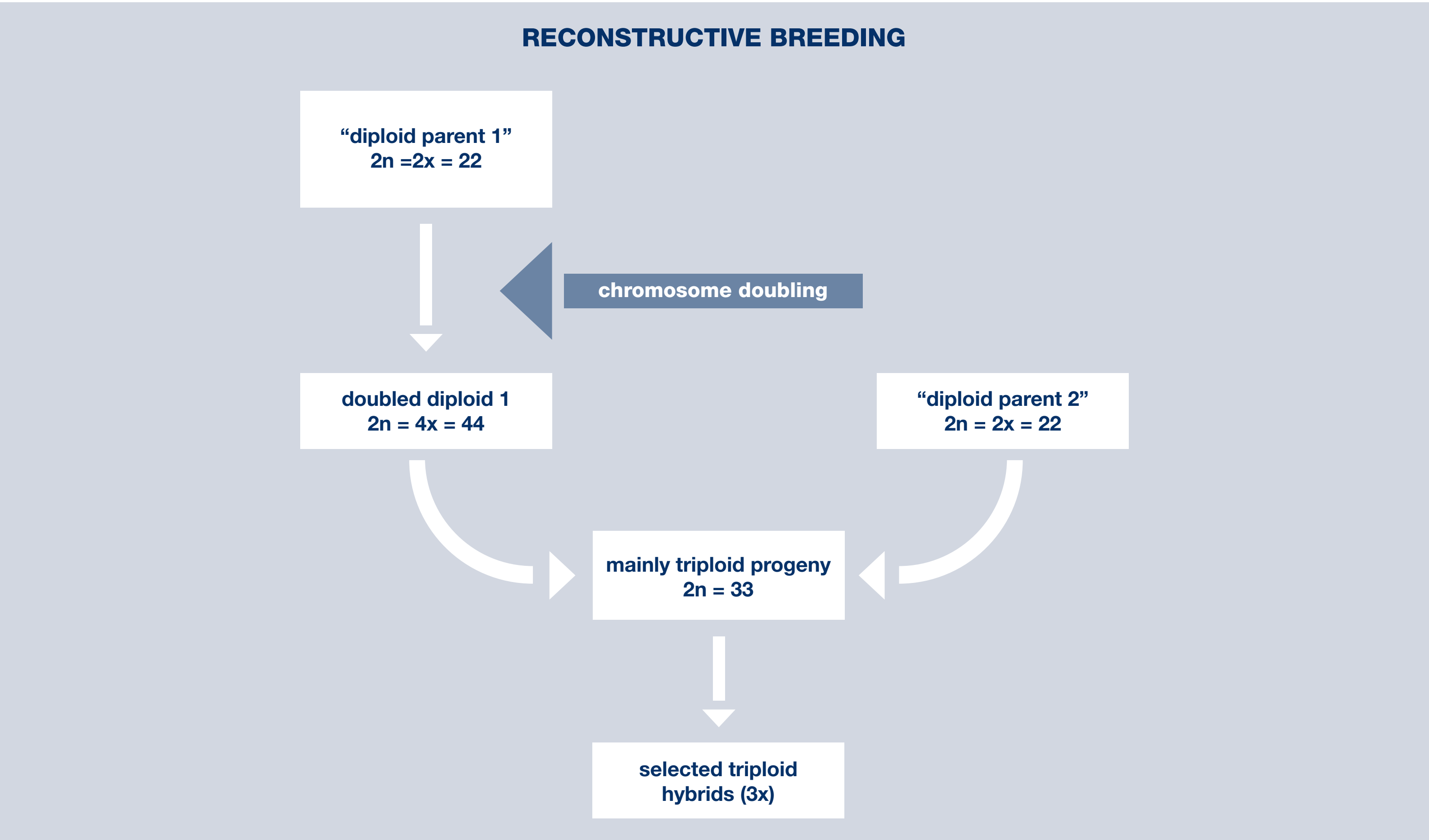
12.1.3.2 The « Reconstructive breeding » approach

Several years ago, an original breeding approach was developed at CIRAD relying on the use of the diploid genetic stocks to create triploid hybrids. Its rationale was corroborated by the recent discovery from genomic studies of the most likely ancestors of the popular triploid cultivars ‘Gros Michel’ and the Cavendish subgroup. This now guides the precise choice of the most relevant parents (the putative ancestors or their close derivatives) to create *de novo* improved variants of the triploid cultivars.

The breeding scheme is also based on a search of the best specific combining abilities between two diploids of which one is the donor of diplo-gametes. Based on complementarities, this approach aims to associate the favourable traits brought by both parents and to maximize the heterozygosity in the triploid progenies. However, since the production of 2n gametes is uncontrolled and fairly rare in diploid clones, a more regular production of 2n gametes is achieved by the use of colchicine to induce tetraploidisation of one of the diploid parents prior to crossing with the other diploid parent, donor of the complementary n-gamete.

Diploid candidates, wild or edible, are selected according to the type of banana to be developed (cooking or dessert), their agronomic and fruit quality characteristics, their behaviour with respect to diseases and their paternal and/or maternal fertility, and their parentage with triploid cultivars. New diploid hybrids that express high resistance to various diseases can also be included in the breeding scheme. Following a primary phase evaluating pest and diseases resistance, agronomic and quality features and fertility, diploids are selected and treated *in vitro* with colchicine for chromosome doubling to form auto-or allotetraploids, whether they are AA or AB cultivars.

Figure 12.2. *Reconstructive Breeding (Source: J. P. Horry)*



The ability to set progeny is strongly linked to gamete fertility, which is highly variable from one to another clone. The gamete fertility of the doubled AA diploids is rather unpredictable: some clones are fertile at both diploid and tetraploid levels. Others are completely sterile at the tetraploid level. Conversely, all interspecific AB clones studied are sterile at the diploid level but have been shown to be systematically male and female fertile at the tetraploid level. These last results confirm previous studies of cytogenetics stating that gamete sterility in AB clones is probably due to incomplete chromosome pairing at meiosis.

An intensive programme of hybridization combining various parents and a larger number of doubled genotypes have strongly indicated that the studied doubled-diploid clones are almost exclusively producing polyploid gametes containing, for a major part, exactly 22 chromosomes. Then, the progenies obtained from doubled-diploids x diploids are essentially triploid, which is the expected objective. These first outcomes validate the original pathways of banana improvement developed by CIRAD.

The advantages of this approach are manifold: the genetic combinations selected at the diploid level are totally or partially preserved through the doubles-diploid. Triploidy confers a high level of sterility. Moreover, breeders can use the wide diversity of the diploid genetic pool, including the very fertile wild parents that enable production of large triploid progenies in which it is easier to make an effective selection. Theoretically, it allows the introduction of new selection criteria at any stage (by using new parents) to respond quickly either to the appearance of new races of pathogenic fungi or to meet other selection objectives.

12.1.4 The Current Major Breeding Programmes

This section is intended to provide a brief status of the major breeding programmes on the following 4 questions:

1. What hybrids have been produced and for what purpose
2. Where are they used
3. How are they used
4. What are the prospects

The main breeding programmes considered in this chapter are CARBAP (Cameroon), CIRAD (Guadeloupe), EMBRAPA (Brazil), FHIA (Honduras) and IITA – NARO (Uganda). Further information on several improved hybrids can be found on the ProMusa information platform at: http://www.promusa.org/Diversity+of+banana+cultivars+portal

12.1.4.1 Breeding at CARBAP (Cameroon)

(the following section was provided by P. Noupadja, CARBAP)

The table below describes the hybrids produced at CARBAP to date, including information on the purpose they were produced, where they are used, how they are used and prospect for further breeding.

Table 12.1. *List of hybrids from CARBAP and descriptions of use to date.*

Hybrid name	Why they were produced	Where is this hybrid used	How is this hybrid mainly used	Prospects of further breeding	Comments or notes on the hybrid
CARBAP 568	Resistance to black leaf streak; dwarfness	Cameroon, Congo, Democratic Republic of Congo, Benin, Togo, Ghana, Central African Republic	Cooking	Improve pulp quality; Breed for resistance to weevil	Dwarf type, early maturity, poor quality of pulp
CARBAP 838	Resistance to black leaf streak	Cameroon, Congo, Democratic Republic of Congo, Benin, Togo, Ghana, Central African Republic	Cooking	Improve pulp quality; Breed for resistance to weevil	Hybrid from French sombre, small fingers, Firm pulp
CARBAP 969	Resistance to black leaf streak	Cameroon, Congo, Democratic Republic of Congo, Benin, Togo, Ghana, Central African Republic	Cooking	Improve pulp quality; Breed for resistance to weevil	Hybrid from French sombre
CARBAP K74	Resistance to black leaf streak	Cameroon	Cooking when green	Improve pulp quality; Breed for resistance to weevil	Secondary triploid hybrid (AAA) from Yangambi km5 and French sombre, Poor pulp quality when ripe; Good for flour when green.

12.1.4.2 Breeding at CIRAD (Guadeloupe, France)

(the following section was provided by J.P. Horry, CIRAD)

The original “reconstructive breeding” strategy developed by CIRAD has been applied to develop triploid hybrids of dessert bananas, both mono (AAA) and interspecific (AAB and ABB). Reconstructive breeding aims to identify good specific combining abilities between diploids and doubled-diploids as donors of diplo-gametes. In addition, it aims to maximize heterosis in the triploid progenies. Parental lines are selected according to their agronomic and fruits characteristics (linked to the type of banana –cooking or dessert, to be developed), their behaviour with respect to diseases and pests, and their male and female fertility at diploid and tetraploid level. Furthermore, the in-depth knowledge of the available genetic resources and the understanding of the relationships between ancestral and cultivated varieties allow selecting the pools of parent lines according to the desired results.

Breeding for AAA dessert banana

Breeding for dessert bananas is conducted in Guadeloupe at CIRAD’s research station in partnership with the French West Indies growers association and its technical institute. Around one thousand hybrids are produced and evaluated annually. Objectives are to develop pest and disease-resistant or -tolerant banana hybrids for the export market to Europe and for domestic markets. Beside resistance to Sigatoka leaf diseases, Fusarium wilt and nematodes, selected hybrids must combine agronomic performance and fruit qualities. Moreover, a strong emphasis is put on fruit quality and postharvest behaviour regarding the heavy constraints required for the export market.

At CIRAD, where the “reconstructive breeding” approach has been prioritized for several years, progress has been made in developing AAA dessert bananas. Several hybrids recently obtained have been released for large-scale evaluation to banana growers in the Caribbean (Dominique, St Vincent, St Lucia, Cuba) and in Australia to supply domestic markets, and two of them (CIRAD 916 and CIRAD 918) are under evaluation in IMTP trials. Four of these hybrids have been evaluated in French Guyana and two of them, CIRAD 916 and 918, have already been adopted by farmers.

CIRAD 925 is to date the most promising hybrid created, combining nearly all the qualities to respond to the export industry requirements. The elite hybrid is presently under large scale evaluation in grower’s fields in Guadeloupe and Martinique to validate its adaptation within the different steps of the export industry sector.

The understanding of the relationships between ancestral and cultivated varieties, allows now more relevant choices of parental combinations. In recent years, focus at CIRAD has been on the use of Mlali type AAcv accessions, putative ancestors of Cavendish and Gros Michel groups. Selected Mlali diploids were tested after chromosome doubling in crosses with AA accessions of the Khai cluster (the other ancestor of these groups). Among the progenies, one individual was obtained, and despite its predictable susceptibility to Yellow Sigatoka, it looks incredibly like Lacatan, the giant and original form of Cavendish, both in terms of plant stature than in fruit quality, thus providing the proof-of-concept for this novel breeding approach.

The drawback of this approach is the lack of resistances within the Mlali group, and their scarcity in the Khai cluster, combined with low gamete fertility of AAcvrs. Therefore, CIRAD engaged in a pre-breeding program to develop fertile improved progenitors containing various sources of diseases resistant genes derived from crosses between edible diploid clones and wild relatives, linked with in-depth studies of the genetic determinism of major traits, combining segregating population analysis, GWAS and QTLs development.

Breeding for AAB/ABB dessert banana

Breeding programs for interspecific hybrids (AAB Silk and Pome, ABB Pisang Awak) aim at the development of new cultivars with Fusarium wilt- and Sigatoka diseases-resistance that retain the organoleptic qualities and productivity of the traditional landraces. The “reconstructive approach” was applied to interspecific breeding at CIRAD, and triploid hybrids were derived from the Kunnan landrace (ABcv), its genomic constitution suggesting that it would come from a cross between a *malaccensis*-derived edible diploid and a *balbisiana* wild relative. Moreover, 'Kunnan' has been proved free from infectious eBSV, allowing its use in crosses. Natural AB clones are sterile but their AABB neo-allotetraploid counterparts obtained through colchicine treatment are both male and female fertile. Tetraploid 'Kunnan' was crossed with AA and BB accessions to generate a triploid. All crosses taken together, 70 hybrids have been field-tested, 61 of which involved wild diploids, *Musa acuminata* or *Musa balbisiana*. It is noteworthy that most of these hybrids bear parthenocarpic (edible) fruit, despite their wild parentage. A common feature within the progenies evaluated is the positive heterosis effect observed. For most characters, mean values observed are significantly superior to the average values of the parents, and in some cases exceed the value of the best parent.

In crosses with wild and edible disease resistant *malaccensis* derivatives, several AAB hybrids were obtained ranging from Silk-like to Mysore-like cultivars and with resistance to Fusarium wilt and Sigatoka leaf streak diseases. On the other side, in crosses with *balbisiana* accessions, several ABB hybrids developed were very similar to 'Pisang Awak' natural clones. The best selected hybrids are presently under evaluation in Guadeloupe.

Within a limited number of hybrids, it has been possible to select some outstanding hybrids from each cross: the AAB '2006-22/III9' with a Mysore morphology, the sweet-acid AAB banana hybrid '2005/25-L9', the Pisang Awak-like '2008/12-I6' and some other weighted bunches ABB hybrids. These promising hybrids need further physiological and physicochemical but might be in in the short term candidates for IMTP trials.

Breeding for cooking bananas

Breeding for cooking bananas follows the "pragmatic" approach and aims at the development of secondary triploid hybrids. CIRAD breeding for cooking-types is conducted in partnership with CARBAP, the ownership of the selected hybrids being shared between the two institutes.

The presence of endogenous integrated sequences of the BSV in the plantain genome and the release of infectious viral particles in the progenies following crosses has long been an obstacle to plantain breeding. However, these viral sequences behave as pseudo-genes and can segregate as heterozygous loci. Recombination between A and B chromosomes during meiosis allowed the development at CARBAP of triploid hybrids that are free from infectious eBSV, obtained from AAAB (primary tetraploids) x AA (primary diploids) crosses. Marker-assisted selection developed by CIRAD (PCR, southern blot) is now exploited to release new cooking hybrids free from any infectious eBSV. 'CARBAP K74' is the first elite plantain-like hybrid obtained at CARBAP in 2012.

12.1.4.3 Breeding at EMBRAPA (Brazil)

(the following section was provided by E. Perito Amorim, EMBRAPA)

Brazilian banana production differs from other global contexts since its main cultivars belong to the AAB Pome/Prata subgroup, in particular, Prata-Anã. Also, especially in the north and northeastern regions of the country, Pacovan and plantain cultivars are also present in Brazilian plantations. These two cultivars, together, make up approximately 80% of the banana cultivated area in Brazil (500,000 ha). The Cavendish subgroup, represented in Brazil by the cultivars Grande Naine, Nanica and Nanicão, are mostly planted in the Southeast region (Vale do Ribeira, São Paulo State) and in the South of Brazil (Northeast of Santa Catarina and Paraná States). The Prata Anã and Pacovan cultivars were developed by EMBRAPA Cassava and Fruits through identification in banana growing areas, evaluation of agronomic potential, national competition assays and other recommendations. As with many other crop species, bananas and plantains are attacked by many phyto-pathogens such as fungi, nematodes and insects. The most important fungi are those causing yellow Sigatoka disease (*Mycosphaerella musicola* Leach), black leaf streak disease (*Mycosphaerella fijiensis* Morelet) and Fusarium wilt (*Fusarium oxysporum* f. sp. *cubense*). Nematodes which lead to huge losses are *Radopholus similis* and *Meloidogyne incognita*, and the most important insect in production areas is the banana weevil borer (*Cosmopolites sordidus*). In Brazil, specifically, Fusarium wilt is the major constraint facing Brazilian banana production, hindering expansion to other areas.

The main cultivars used by banana growers (Bananas: Prata-Anã, Pacovan, Silk, Grande Naine and plantains: Terra Maranhão, Terrinha and D'Angola) are susceptible to yellow Sigatoka and black leaf streak diseases. With regard to Fusarium wilt, Grande Naine and plantains are resistant, Silk is highly susceptible and the remaining cultivars are moderately susceptible. In the specific case of plantains, borer weevil and nematodes are the main limiting factors as far as maintaining the plants in the field is concerned, since they are highly susceptible.

EMBRAPA carries out the only banana breeding program in Brazil, initiated in 1976, by developing its germplasm collection. It is a product of national and international collections. This program has developed the following cultivars through crosses: BRS Caprichosa, BRS Garantida, BRS Japira, BRS Pacovan Ken, BRS Preciosa, BRS Princesa, BRS Tropical, BRS Vitória, BRS Pioneira, BRS Platina and BRS Pacoua. EMBRAPA has also recommended three cultivars from collections or identification of mutations: BRS Conquista, BRS Pelipita, BRS Thap Maeo and BRS SCS Belluna.

These cultivars are used by growers in different Brazilian regions, mostly in the North and Northeast regions, where these same cultivars are responsible for the income of small producers, especially in areas where the use of technology is still at its infancy. It is worth highlighting that the two most important Brazilian cultivars – Prata Anã and Pacovan – which together are responsible for approximately 80% of the cultivated area were identified and recommended by the banana genetic breeding program at EMBRAPA.

EMBRAPA uses three main strategies of conventional breeding:

1. Crosses between wild diploids to develop improved diploids resistant to main pests and diseases and good agronomic characteristics: EMBRAPA has a collection with 30 improved diploids, all resistant to Fusarium wilt and yellow Sigatoka, and most of them, also resistant to black leaf streak
2. Crosses between improved diploids and commercial triploid cultivars (Prata type, Silk and Cavendish) to develop tetraploid hybrids
3. Crosses between improved diploids and tetraploid hybrids to develop triploid cultivars: This strategy is the main current focus and hundreds of genotypes are being evaluated in the many experimental areas of EMBRAPA.

As far as biotechnological tools are concerned, EMBRAPA has many different strategies which support the conventional breeding program:

1. Plant x biotic factors interaction studies (*Mycosphaerella musicola* / *Mycosphaerella fijiensis* / *Fusarium oxysporum* f. sp. *cubense*): Potential candidate genes associated to resistance to these three diseases have been identified via NGS (Next Generation Sequencing) - RNA-seq techniques. These genes are being validated through RT-qPCR for further use in cisgenics and marker-assisted selection (MAS). In the case of cisgenics, EMBRAPA has identified tissue-specific promoters (leaf and root). New interactions, however, are also being planned (nematodes and borer weevil)
2. *Musa* x abiotic factors interaction studies, especially concerning drought tolerance and post-harvest are ongoing using a proteomics approach. Many candidate genes have been identified as being associated in metabolic networks as hub proteins involved in drought tolerance and will be sought out for use in MAS. Similar work is being carried out for fruit ripening and finger drop, especially for Prata type cultivars
3. Diversity and genetic structure of *Mycosphaerella musicola*, *Mycosphaerella fijiensis*, *Fusarium oxysporum* f. sp. *Cubense*, *Meloidogyne incognita* (root-knot nematode) and *M. javanica* populations with the objective of creating a detailed map of the distribution of these pests and diseases in main banana producing areas in Brazil. This work will be followed by the identification of most aggressive or virulent populations for use in inoculations aiming for the early selection of resistant or tolerant genotypes. Protocols for early selection were developed by EMBRAPA and are being applied

4. Duplication of chromosomes from wild and improved diploids: Many diploids were duplicated and the number of chromosomes confirmed by flow cytometry and cytogenetics. These auto-tetraploids were characterized for a series of agronomic characteristics and identified as promising, which were then crossed with diploids for the development of secondary triploids and are now under evaluation in the experimental areas of EMBRAPA
5. Somatic embryogenesis and cell suspensions: EMBRAPA has developed protocols for generating cell-suspensions and plant regeneration. Work with molecular markers show that these suspensions give rise to genetically stable plants
6. Induction of mutation using gamma rays and anti-mitotic agents: The focus here is to identify short stature plants and recently induce mutants with resistance to Fusarium wilt and to yellow Sigatoka and black leaf streak. Results so far seem promising.

Preventive breeding is also an objective of EMBRAPA, especially regarding *Fusarium oxysporum* f. sp. *cubense* Tropical race 4. EMBRAPA will send its elite germplasm for testing at PRI / Plant Research International - University of Wageningen – The Netherlands - and the Department of Agriculture, Fishery and Forest in Australia (DAFF), which are our main partners in this task.

EMBRAPA also has a partnership with the BGPI research unit (Biology and Genetics of Plant-Pathogen Interactions) of CIRAD- Montpellier, France, in activities to identify BSV species in the banana germplasm collection at EMBRAPA and also main banana producing areas in Brazil, since this data is practically unknown and necessary for main germplasm exchange activities.

Since EMBRAPA´s breeding program is one of the oldest, with great history and knowledge acquired/ generated, EMBRAPA is in the forefront of banana breeding and has great potential to collaborate with international partners focusing on developing cultivars resistant to main pests and diseases possessing sensorial characteristics aligned with producers and consumers demands.

It is worth mentioning that since Brazil is a continental country, it has a wide range of edaphoclimatic conditions which allows for the evaluation and selection of genotypes in the many different environments. EMBRAPA has a broad network of partners and its own bases able to test new hybrids from regions with elevated pluviometric indices to dry areas, environments with temperate climate to tropical climate, areas from sea level to high altitudes, areas with bananas as monoculture or in consortium, among many other contrasts.

Table 12.2. *List of hybrids from EMBRAPA and descriptions of use to date.*

Hybrid name	Why they were produced	Where is this hybrid used	How is this hybrid mainly used	Prospects of further breeding	Comments or notes on the hybrid
BRS Tropical	Resistant to yellow Sigatoka and tolerant to Fusarium wilt	Brazil	Dessert	Convert to triploid and Improve resistance to black leaf streak and Fusarium wilt (BRS Tropical crosses with improved diploid). Select Dwarf type	Silk type (AAAB)
BRS Princesa	Resistant to yellow Sigatoka, black leaf streak and Fusarium wilt	Brazil	Dessert	Convert to triploid (BRS Princesa crosses with improved diploid). Select Dwarf type	Silk type (AAAB)

Hybrid name	Why they were produced	Where is this hybrid used	How is this hybrid mainly used	Prospects of further breeding	Comments or notes on the hybrid
BRS Platina	Resistant to yellow and Fusarium wilt and moderately resistant to black leaf streak	Brazil	Dessert	Convert to triploid (BRS Platina crosses with improved diploid). Improving shelf life	Pome/Prata type (AAAB)
BRS Pacoua	Resistant to yellow Sigatoka and Fusarium wilt and moderately resistant to black leaf streak	Brazil	Dessert	Convert to triploid (BRS Pacoua crosses with improved diploid). Select Dwarf type	Pome/Prata type (AAAB)
BRS Caprichosa	Resistant to yellow Sigatoka, black leaf streak and Fusarium wilt. Moderately resistant to Weevil and nematodes	Brazil	Dessert	Select Dwarf type	Pome/Prata type (AAAB)
BRS Garantida	Resistant to yellow Sigatoka, black leaf streak and Fusarium wilt. Moderately resistant to Weevil and nematodes	Brazil	Dessert	Select Dwarf type	Pome/Prata type – Pome (AAAB)
BRS Vitória	Resistant to yellow Sigatoka, black leaf streak and Fusarium wilt	Brazil	Dessert	Convert to triploid (BRS Vitória crosses with improved diploid). Select Dwarf type	Pome/Prata (AAAB)
BRS Japira	Resistant to yellow Sigatoka, black leaf streak and Fusarium wilt. Moderately resistant to Weevil	Brazil	Dessert	Convert to triploid (BRS Japira crosses with improved diploid). Select Dwarf type	Pome/Prata type (AAAB)
BRS Pacovan Ken	Resistant to yellow Sigatoka, black leaf streak and Fusarium wilt. Moderately resistant to Weevil	Brazil	Dessert	Select Dwarf type	Pome/Prata type (AAAB)
BRS Preciosa	Resistant to yellow Sigatoka, black leaf streak and Fusarium wilt	Brazil	Dessert	Select Dwarf type	Pome/Prata type (AAAB)
BRS Pioneira	Resistant to yellow Sigatoka and Moderately resistant to Weevil	Brazil	Dessert	-	Pome/Prata t ype (AAAB)

12.1.4.4 Breeding at FHIA

The limited information in Table 12.3 below is extracted from a presentation made by FHIA at FAO, Rome, on 23 September 2014. Links to Promusa pages on the FHIA hybrids are also provided.

Table 12.3. *List of hybrids from FHIA and descriptions of use to date.*

Hybrid name	Why they were produced	Comments or notes on the hybrid
FHIA 01	Resistant to Sigatoka and FOC-TR4	http://www.promusa.org/FHIA-01
FHIA 03		http://www.promusa.org/FHIA-03
FHIA 17		http://www.promusa.org/FHIA-17
FHIA 18		http://www.promusa.org/FHIA-18
FHIA 20		http://www.promusa.org/FHIA-20
FHIA 21		http://www.promusa.org/FHIA-21
FHIA 23		http://www.promusa.org/FHIA-23
FHIA 25	Resistant to Sigatoka and *Foc*-TR4	Pome type http://www.promusa.org/FHIA-25
SH4037	PreBreeding	

12.1.4.5 Breeding at IITA (Nigeria/Uganda)

(the following section was provided by R. Swennen, IITA)

Table 12.4 below describes the hybrids produced at IITA to date, including information on the purpose they were produced, where they are used, how they are used and prospect for further breeding. Countries that received the material in 2014-2015 are listed. It is still too early to speak of use, as material has only been delivered for testing. Only in IITA are some of the hybrids that are being used by farmers.

Table 12.4. *List of hybrids from IITA and descriptions of use to date.*

NOTE: all hybrids below are IITA hybrids, but NARITAs are NARO/IITA hybrids.

Hybrid name	Why they were produced	Where is this hybrid used	How is this hybrid mainly used	Prospects of further breeding	Comments or notes on the hybrid
TMP2x 2829-62; TMP2x 1297-3	Host plant resistance to black leaf streak	Nigeria, Cameroon, Uganda	Plantain derived; breeding	Integrating/ confirmation for weevil/nematode/ Fusarium resistance and adding dwarfism and higher provitamin A	Fields established to gather data for registration
TMp2x 9128-3	Very long pendent bunch	Nigeria, Uganda, Puerto Rico, Tanzania	breeding	Integrating/ confirmation for weevil/nematode/ Fusarium resistance and adding dwarfism and higher provitamin A	Fields established to gather data for registration
BITA 2; BITA 3; PITA 14	Host plant resistance to black leaf streak, yield	Nigeria, Cameroon, Ghana, Puerto Rico	Plantain-like derived; breeding; Cooking	Integrating/ confirmation for weevil/nematode/ Fusarium resistance and adding dwarfism and higher provitamin A	Fields established to gather data for registration

Hybrid name	Why they were produced	Where is this hybrid used	How is this hybrid mainly used	Prospects of further breeding	Comments or notes on the hybrid
PITA 1; PITA 4; PITA 5; PITA 7; PITA 8	Host plant resistance to black leaf streak, yield	Nigeria, Ghana	Plantain derived; breeding; Cooking	Integrating/ confirmation for weevil/nematode/ Fusarium resistance and adding dwarfism and higher provitamin A	Fields established to gather data for registration
PITA 2; PITA 16	Host plant resistance to black leaf streak, yield	Nigeria, Puerto Rico	Plantain derived; breeding; Cooking	Integrating/ confirmation for weevil/nematode/ Fusarium resistance and adding dwarfism and higher provitamin A	Fields established to gather data for registration
PITA 3	Host plant resistance to black leaf streak, yield	Nigeria, Ivory Coast	Plantain derived; breeding; Cooking	Integrating/ confirmation for weevil/nematode/ Fusarium resistance and adding dwarfism and higher provitamin A	Fields established to gather data for registration
PITA 6; PITA 11; PITA 13; PITA 18	Host plant resistance to black leaf streak, yield	Nigeria	Plantain derived; breeding; Cooking	Integrating/ confirmation for weevil/nematode/ Fusarium resistance and adding dwarfism and higher provitamin A	Fields established to gather data for registration
PITA 9	Host plant resistance to black leaf streak, yield	Ghana	Plantain derived; breeding; Cooking	Integrating/ confirmation for weevil/nematode/ Fusarium resistance and adding dwarfism and higher provitamin A	Fields established to gather data for registration
PITA 10	Host plant resistance to black leaf streak, yield	Puerto Rico	Plantain derived; breeding; Cooking	Integrating/ confirmation for weevil/nematode/ Fusarium resistance and adding dwarfism and higher provitamin A	Fields established to gather data for registration
PITA 12	Host plant resistance to black leaf streak, yield	Nigeria, Ghana	Plantain derived; breeding; Cooking	Integrating/ confirmation for weevil/nematode/ Fusarium resistance and adding dwarfism and higher provitamin A	Fields established to gather data for registration
PITA 17; PITA 21; PITA 22; PITA 23; PITA 24; PITA 26; PITA 27	Host plant resistance to black leaf streak, yield	Nigeria, Ivory Coast, Ghana, Cameroon, Puerto Rico, Burundi, Rwanda, Congo, Benin, Comoros	Plantain derived; breeding; Cooking	Integrating/ confirmation for weevil/nematode/ Fusarium resistance and adding dwarfism and higher provitamin A	Fields established to gather data for registration

Hybrid name	Why they were produced	Where is this hybrid used	How is this hybrid mainly used	Prospects of further breeding	Comments or notes on the hybrid
PITA 25	Host plant resistance to black leaf streak, yield	Nigeria, Comoros, Congo	Plantain derived; breeding; Cooking	Integrating/ confirmation for weevil/nematode/ Fusarium resistance and adding dwarfism and higher provitamin A	Fields established to gather data for registration
NARITA 1; 2; 4; 5; 6; 7; 11; 12; 13; 14; 15; 17; 18; 19; 20; 21; 22; 23; 24; 25; 26	Host plant resistance to black leaf streak, yield	Uganda, Tanzania	Cooking	Integrating/ confirmation for weevil/nematode/ Fusarium resistance	Multilocational trials starting in Uganda and Tanzania in 5 locations, evaluation by consumers planned in these 5 sites
NARITA 3; 8; 9; 10; 16	Host plant resistance to black leaf streak, yield	Uganda, Tanzania	Juice/beer	Integrating/ confirmation for weevil/nematode/ Fusarium resistance	Multilocational trials starting in Uganda and Tanzania in 5 locations, evaluation by consumers planned in these 5 sites

12.1.5 Biotechnologies and breeding

In a comprehensive overview, Ortiz and Swennen reviewed the recent advances in biotechnology and their actual and future applications in banana breeding (Ortiz and Swennen 2013). This section is limited to the biotechnological tools that are routinely used in most banana breeding programs.

12.1.5.1 Tissue culture

In vitro micropropagation of banana is now widely used for germplasm exchange and also to supply clean planting materials to farmers and intensive cropping systems. Even if tissue propagules are more expensive than traditional suckers, the yield increase may compensate for the investment. Applied in most breeding programs, *in vitro* embryo rescue assists in enhancing germination of banana seeds resulting from controlled pollination involving cultivars, often containing abnormal embryos or absent endosperm.

12.1.5.2 Cytogenetics

Cytogenetics research in *Musa* has been developed since the early 1920s to elucidate the genetic structure of the polyploid complex, from chromosome numbering to the study of chromosome pairing during meiosis. The development of *in situ* hybridisation (FISH and GISH) allows for a precise deciphering of the chromosome rearrangements and pairing between the homologous A and B genomes. In a recent study, Jeridi showed that gamete sterility in AB clones is probably due to incomplete chromosome pairing at meiosis: the authors distinguished two subgroups of pairing chromosome behaviour, one of eight chromosome sets displaying high (but not complete) pairing affinity, suggesting a high degree of homology between A and B chromosomes, and a second of three chromosome sets presenting low pairing affinity, indicating a lower degree of homology (Jeridi et al. 2012). This result also supports the hypothesis that recombination does occur between A and B genomes for at least eight chromosomes of eleven. Flow cytometry is routinely used to characterize genetic resources in genebanks of parents and progenies in most breeding programs.

12.1.5.3 DNA markers

In recent decades, several genomic tools have been successfully used to decipher the complexity of the *Musa* genepool. Molecular markers have not only proven to be effective to distinguish between genotypes, but moreover have provided a clear understanding of the history of the domestication of the crop, from the ancestor wild species to the present day cultivars. The acquired knowledge of the probable diploid ancestors of most triploid cultivars allows us to build breeding schemes that mimic the sequence of crossings and selections that occurred over several millennia. DNA markers (SSR, DArTs) are now routinely used to characterize genebank materials, and are used in breeding program to check the conformity of breeding materials.

12.1.5.4 Genomics

Recent advances in *Musa* genomics, from the first complete sequence of the *Musa* genome published in 2012 to the ongoing re-sequencing of hundreds of genotypes will increase the efficiency of banana breeding. The *Musa* genome can now be deeply explored for the characterization of desirable genes involved in important agricultural traits as a prelude to their use in marker assisted selection. Priorities for the GTG of MusaNet in this area include improved gene annotation and elucidation of gene function through analysis of gene expression in specific conditions, mutation/tilling, GM approaches, proteomics and metabolomics. The very fine structure of the genome, the arrangement of the chromosomes and of the DNA sequences can now be studied with an unprecedented precision, adding to the characterization of the genetic complex and the understanding of the evolutionary pathways. For banana improvement, this approach is particularly important in a biological context of gamete sterility (and difficulties to get large quantities of seeds) for which use of recombination and implementation of introgression strategies remain the greatest challenge.

12.1.5.5 Marker assisted selection (MAS)

Marker assisted selection is only just beginning in banana breeding. From the recent and future advances in genomics, MAS will eventually enhance and accelerate genetic improvement in banana. However, presently, its main application relates to the early selection of non-infectious eBSV alleles in interspecific crosses involving *balbisiana*-derived material.

12.1.5.6 Genetic engineering

Genetic engineering of bananas began 20 years ago, with expectations to accelerate banana breeding by directly improving sterile cultivars that appear untreatable through cross-breeding. The main objectives are to increase the micronutrient content to alleviate malnutrition in East African countries and to incorporate traits that are lacking in the *Musa* genepool. Among the latter are the genes for resistance to viruses and *Xanthomonas* wilt, for which no reliable resistance source seems to exist. Moreover, strategies for the acquisition of resistance to other diseases by genetic transformation are now available, like the use of protease inhibitors and *Bacillus thuringiensis* genes to develop resistance to weevils and nematodes, or the identification of resistant genes such as chitinases, antifungal proteins, etc., against Sigatoka diseases and Fusarium wilts.

The goal is to incorporate in the genome relevant DNA-sequences that should express a desired improvement. While the incorporation of genes has been proven to be quite feasible, its desired expression depends on the extraordinary complex dynamics in the transciptome and proteome. Progress has recently been made in that domain for model plants such as *Arabidopsis*, and it can be expected that genetic engineering of bananas will in the coming years integrate the necessary precise mechanisms for the desired expression of genetically modified cultivars.

Recent developments of genome editing with engineered nucleases, such as CRISPR technology, which does not involve taking genes from one organism and implanting them in another, appears to be a promising approach for banana breeding in the near future. In this respect, an interesting outlook will be that such genetically modified diploids could enter the breeding schemes at appropriate phases.

12.1.5.7 Induced mutation techniques

Work has also been carried out using mutation to expand the range of *Musa* diversity available for breeding. Spontaneous somatic mutations have long played an essential role in the speciation and domestication of bananas. In an effort to mimic this natural occurring process, mutagenic agents such as radiation and certain chemicals have been used to induce mutations at a higher frequency and generate genetic variation from which desired mutants may be selected. Several variants and putative mutants have been identified at the International Atomic Energy Agency (IAEA) in Austria for release or further confirmation trials. One example is a the variety Klue Hom Thong KU1 from Thailand, which was obtained by treating tissue cultures with gamma rays at 2.5 krad (25 Gy), and was selected for its larger bunch size and cylindrical shape. Even though the traditional shoot-tip mutation-induction techniques applied to genetic improvement has produced some useful mutants, there are some limitations, e.g. treated shoot tips show a high degree of chimerism and because of the random nature of mutation induction, many plants need to be screened, which can be expensive, laborious and site-specific. But now we know that to overcome chimerism, embryogenic cell suspension (ECS) is the material of choice (as embryos are formed from single cells). Early mass screening techniques (*in vitro* or in greenhouse) are being used to increase efficiency before validating results under field conditions (Roux, 2004). Thanks to recently developed next generation sequencing techniques, there is an increased interest in collecting mutants to understand *Musa* gene structure and function.

SECTION 12.2 GENETIC IMPROVEMENT – WHERE WE WANT TO GO

The products of existing improvement programmes, drawing on sources of biotic and abiotic stress resistance from wild and edible genotypes, are still not meeting important criteria, such as (1) adaptation to recurring extreme weather-conditions, such as drought and cold, mainly in peripheral areas of the banana biotope, and (2) widely and/or regionally acceptable fruit quality.

12.2.1 Addressing abiotic stresses

Variation among wild and edible *Musa* species offers a wide spectrum of promising phenotypes. For instance, the ecology of various wild species suggests that sources of resistance to abiotic stresses exist in Eumusa along the northern altitudinal periphery of its distribution, including mechanisms for tolerance to cold (*M. sikkimensis, M. basjoo, M. thomsonii*), water-logging (*M. itinerans*), and drought (*M. balbisiana*, *M. nagensium*). The physiological and genetic background of the quite diverse ex-section Rhodochlamys members, adapted to monsoon conditions, should also be investigated. Recent collecting expeditions in northern India, Malaysia and Indonesia suggest that other poorly known or unexplored areas of diversity (such as cultivars in the species *M. balbisiana* or in the *acuminata* subspecies) are likely to harbour other interesting agronomic characteristics. Unfortunately, many such underexplored specimens (with the remarkable exception of *M. balbisiana*) are hardly expressing their phenotypic potential outside their usual habitat, as is the case in the common lowland banana collections, or they even disappear after a few years. And inter-specific F1 progeny derived from crossing such specimens with common wild AA/BB parents would not be fertile in most cases. *In situ* extraction of DNA in view of further analyses and eventual integration in genetic improvement may be a more promising prospect.

Breeders are well aware of this potential, but there is the need for a programme and funding of such special operations.

A remarkable exception is the adaptation of some triploid groups such as Cavendish, grown under a large range of latitudes and ecologies, an adaptability that is retrieved in the edible *acuminata* cultivars of East Africa and neighbouring islands. Genetic diversity in these diploids is very low, suggesting a very narrow genetic base; however, they are cultivated from sea level to the slopes of Mount Kenya, at more than 1000 m above sea level. This suggests that genetic resources adapted to extremely different ecologies are available for the breeders, even within the *acuminata* genetic stocks.

12.2.2 Addressing the desired plant phenotype and fruit quality

Although there are now many hybrids that have been developed to address issues such as pests and diseases, fruit quality has often been neglected. Consequently, the products are generally not meeting the fruit quality to which the diverse local consumers are accustomed. Each region and each country will have specific needs and requirements.

The term "fruit quality" should be considered in its broadest sense, thereby not only meaning "organoleptic quality" but also the entire chain from farm to market. For example, the truck transport of bunches over relatively long stretches of local roads means that only physically resistant fruits are convenient on the markets. Early ripening and premature fruit dehiscence are also rejected. Fruit post-harvest qualities are even more constraining for exportation, where fruits must resist several weeks of shipment.

Consequently, the construction of synthetic diploids in breeding programs should not only catch the sources of disease/pest resistance, but also include fruit quality in its broadest sense. Such range of qualities apparently exists among the numerous edible AA but has been poorly explored from a genetic perspective. Characterization of fruit quality in the diploid genetic pool and the elucidation of the genetic basis are the priorities to address and monitor these traits in breeding programs.

Yet only a fraction of the genetic diversity in the genus *Musa* is being used, even within *balbisiana* and *acuminata* species. Breeding programmes need to broaden their genetic base to address the numerous challenges of banana breeding, considering both pests and diseases, fruit quality (organoleptic and post-harvest) and agronomic features (e.g. yield, adaptation to miscellaneous and changing environments).

SECTION 12.3 GENETIC IMPROVEMENT – HOW WE WILL GET THERE

12.3.1 Preamble

A fully concerted banana genetic improvement programme on global scale cannot be realized. Such a programme would imply that the participants constantly share their detailed operational strategy for each end-product at which they are aiming: the satisfactory hybrid. The programmes would probably not have problems in the ideal situation of an assured abundant financing, but that is far from the case for the banana crop. Banana improvement programmes therefore operate in a competitive configuration which obliges them to protect their precise methodology in the hope that 'their' product, when successful, would produce a return to finance the continuation of their efforts. One can use the term "property rights" in this case.

Nevertheless, two phases of the improvement open the prospect for sharing at global scale:

- The pre-breeding phase, with a common sharing of the basic plant material (and its performance) such as selected edible diploids and even partially improved diploids
- The post-breeding phase, with the testing of hybrids in different environmental and cultural conditions. The IMTP principle could be used as a convenient instrument.

Both phases could be facilitated via coordination at global scale.

12.3.2 The Douala Workshop on Musa Breeding, 28-30 October 2013

For the first time in the history of banana research, a representative group of scientists involved in genetic improvement came to an agreement on collaborative activities during the workshop "Multi-centre Planning on Banana / Plantain Improvement" in October 2013 at Doula, Cameroon.

The workshop was co-organized by CARBAP, Bioversity and IITA and financed by the Bill and Melinda Gates Foundation (BGMF) and the CRP-RTB. The major actors were the leading *Musa* research and breeding programmes and experts from allied crops and disciplines.

Quoting from the workshop report, "the primary objective of the workshop was to establish a consensus opinion on the long-term strategy (and key priorities) for "accelerated" banana crossbreeding focused on outputs for Africa that would also have relevance for other regions. In addition, the workshop aimed to define the respective roles of various interested parties, and establish the framework for a concept note (focusing on breeding plantain-like hybrid cultivars)".

The Concept Note, entitled "Program for improved plantain for Sub-Saharan Africa (PIP-SSA), a global breeding partnership", covers all the aspects of such an undertaking at a global scale. The pre-and post-breeding tasks, which call for advanced sharing of material and results were particularly developed. Collaboration for the breeding activities was outlined as far as possible and the means for sharing the rapidly growing knowledge on molecular genetics (omics datasets, genetic information on genes-traits correlation, etc.) for their integration in breeding programmes were systematically proposed.

While it is mainly focused on the important subgroup of AAB Plantain in Africa, the Concept Note can indeed be used as a model for similar collaborative programs in all other regions.

The table below summarizes the future objectives within the breeding programmes.

Table 12.5. *Objectives and proposed actions regarding genetic improvement.*

Objectives	Proposed actions
1. Meeting breeders' needs of parental stocks to address biotic and abiotic stresses	• Explore and collect genetic stocks in poorly explored areas and diverse ecologies • Characterize and evaluate genetic stocks of potential interest in diverse ecologies • Make available a wide spectrum of genetic resources to breeders, including outsider specimens of interest
2. Improving knowledge of fruit quality in parental stocks	• Characterize fruit qualities of diploid germplasm • Foster research on the genetics of fruit quality traits
3. Improving pre-breeding at a global scale	• Share knowledge among the breeders of the performance of genetic stocks used in breeding • Facilitate the exchange of basic genetic stocks of breeding interest • Encourage and facilitate the sharing of improved diploids between breeding programs
4. Improving the evaluation and adoption of improved varieties	• Establish a secure network for the evaluation of novel varieties, such as IMTP, including the respect of IP rights of the breeders • Evaluate hybrids under diverse environmental and cultural conditions